NAVSEA
CARDEROCK
Surface Warfare Center Division

Overview of Composites Structures R&D at Carderock Division

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Structures and Composites Department
Code 65

Brief to JTEG Meeting on
"Composite Manufacturing and Repair"
4-6 Nov 2003

Outline

- **Who we are**
- **Recent research topics**
  - Material Qualification
  - Advanced Material Processing (Intelligent VARTM, co-infusion)
  - Joint Testing and Analysis
  - Composites Failure Modeling (MCT, DYCOSS)
  - Damage Determination for Defect Assessment
  - Large Structure Collapse Prediction and Testing
- **Summary**

Carderock Division, Headquarters

Mission

Research and development, test and evaluation, fleet support, and in-service engineering for surface and undersea vehicle hull, mechanical, and electrical (HM&E) systems and propulsors;
logistics research and development;
and support to the Maritime Administration and the maritime industry

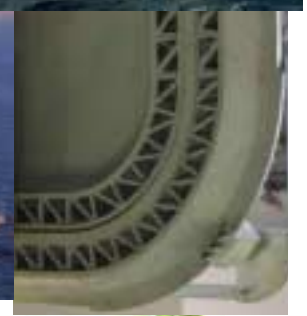
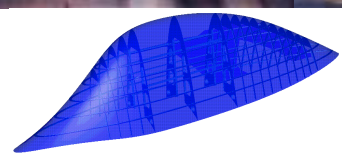
Structures and Composites Department - Mission

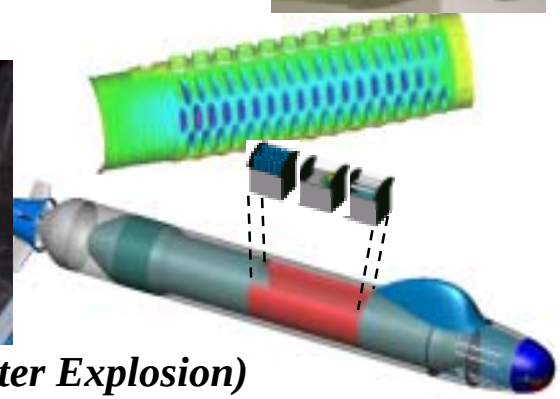
Mission:

- *Conduct full spectrum RDT&E for Surface Ship and Submarine Structures*
- *Provide Support to the Marine Industry & Related Areas*







Areas of Responsibility:

- *Advanced Concepts / Ship Design*
- *Structural Design / Analysis / Reliability*
- *Composite Structures Technology*
- *Lab / Large Scale / At-Sea Test & Evaluation*

Uniqueness:

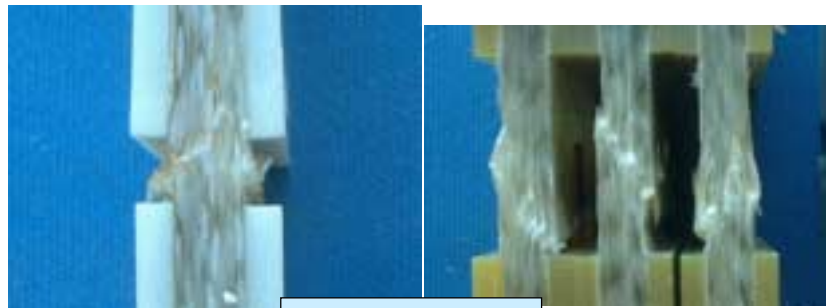
- *Expertise in Numerical & Physical Structural Modeling (Metals & Composites)*
- *Historical Experience in Hull Loads (Seaway, Ice, Air and Underwater Explosion)*
- *Established Structural Reliability Bases for Affordable Design*
- *Large marine composite R&D capability (35 scientists, engineers and technicians)*

Material Qualification

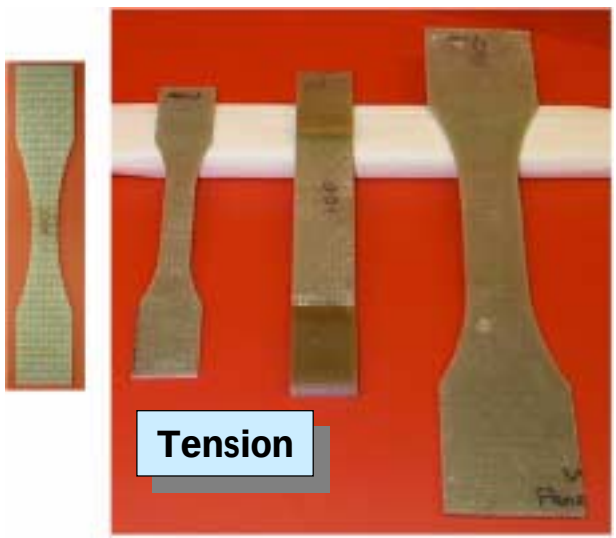
- Develop standard material qualification procedures for the determination of statistically-based composite mechanical property design values for Naval applications.
  - Test methods
  - Material batch requirements
  - Specimen replicate requirements
  - Statistical data analysis methods
  - Environmental conditioning methods (accelerated aging)

- Basis
  - Navy test data and procedures (AEM/S, etc.)
  - ASTM test methods
  - Mil Handbook 17 (DOD/FAA-developed document)

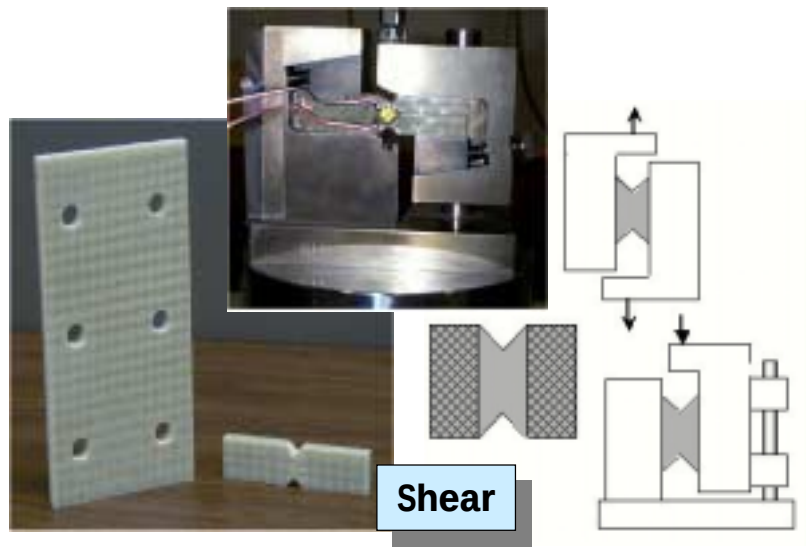
Material Qualification:
Aerospace Standards vs. Marine Composites



Compression



Tension



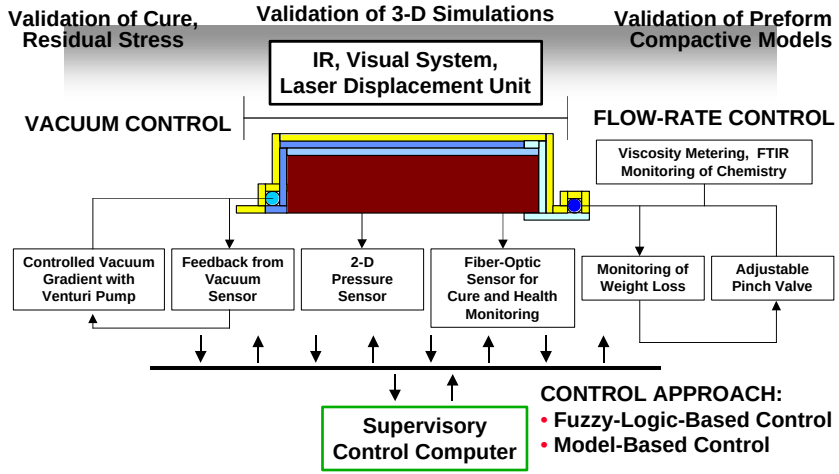
Shear

Material Qualification: *Batch to Batch Variability*

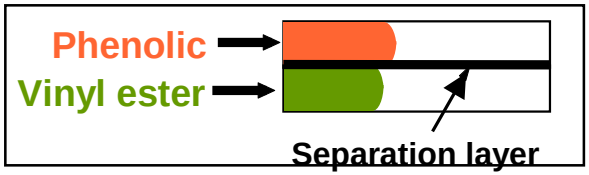
- Recent test results challenge previous views of material equivalency for "standard" Navy laminate material (E-glass woven roving/vinyl ester) with VARTM process
  - Potential sources of batch-to-batch strength variability
    - Glass lot
    - Glass manufacturer (sizing)
    - Resin lot
    - Catalyst and other cure agents
    - Ply orientation errors
    - Uniformity of environmental conditioning
    - Variation in fiber volume from VARTM process
  - Potential sources of general data scatter (modulus and strength)
    - Change in test technician (test facility was constant)
    - Strain gage size (with respect to unit cell size)
    - Test specimen size (with respect to unit cell size)

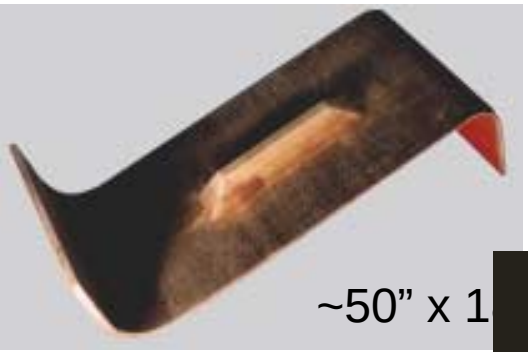
Advanced Material Processing: Intelligent VARTM Processing

ONR National VARTM Testbed



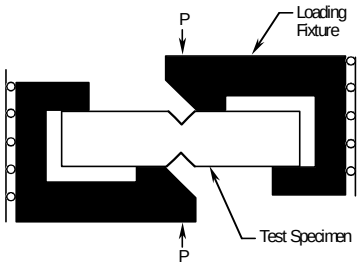
Advanced Material Processing: Co-Injection Resin Transfer Molding (CIRTM)





- Phase I demonstrated process using
  - 510A as structural resin
  - J2027 phenolic as fire barrier resin
  - 24 oz woven roving as reinforcement
- Flat Panel Development
  - Validated Co-infusion process
  - Validated structural properties and durability (SBS & wedge test)
- Cone Calorimetry Fire Performance
- Developed Methodology for Residual Strength Design after Fire
- Demonstrated Complex Fabrication on Z-Stiffener
- Demonstrated 3-Layer CIRTM with Intumescent layer
- Manufactured full scale room corner fire test specimen

Joint Testing and Analysis



Fundamental Property Tests

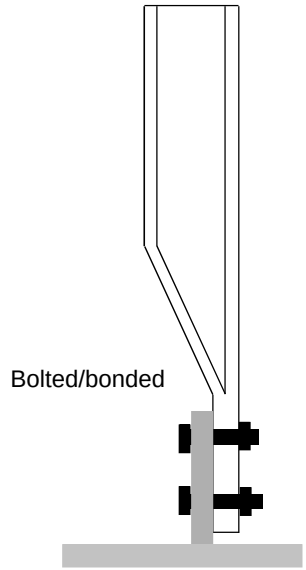
Basic material data

Complex Stress Tests

Joint-related data

Parametric Tests

Simple joint configurations
Parametric effects
Analysis/design development



Element Tests

Realistic joint details and loads
Analysis/design validation

ANALYSIS AND DESIGN METHODS

Joint Testing and Analysis

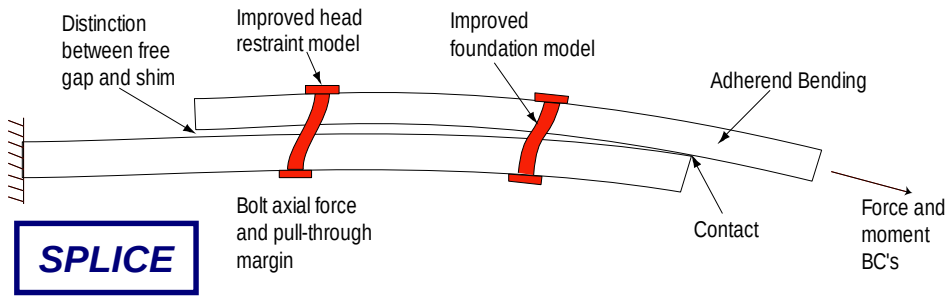
- **Objective**

  Develop design guidelines and verify analysis tools for joints in marine composite applications

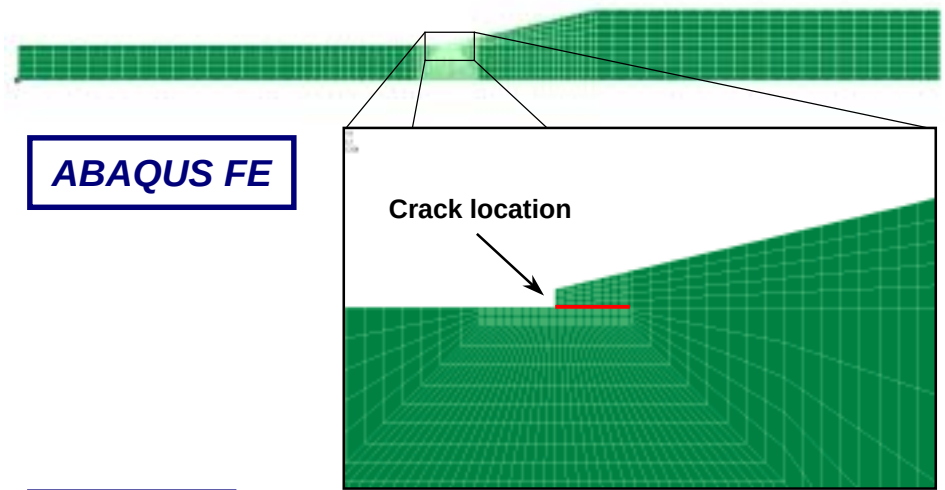
- **Joint parametric testing completed**
  - Bolted joints
    - Single and double lap configurations
    - Parameters include *d/t*, bolt pre-load, edge distance, gap thickness and filler material
  - Adhesively bonded joints
    - Single and double lap configurations
    - Parameters include adherend thickness, adhesive thickness, taper ratio, load angle
  - Secondarily bonded (integral) joints
    - Scarf and doubler configurations
    - Parameters include thickness and taper ratio
    - Second round of testing planned involving moisture conditioning, fatigue

Joint Testing and Analysis

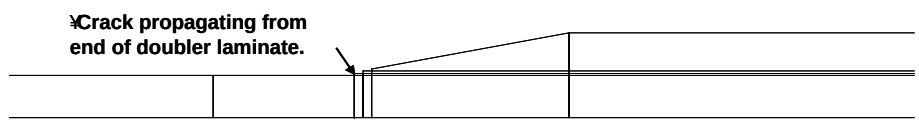
- **Current analytical focus**
  - SPLICE design tool for bolted joints
    - Mathematica notebook
    - Includes bolt flexibility and plate bending
    - Evaluates all bolt and plate failure modes
  - Fracture mechanics analysis for secondarily bonded (integral) joints
    - Finite element method via virtual crack closure technique
    - Sublaminate analysis code (SUBLAM)
- **End products**
  - Guidance document for joint design
  - Guidance document for joint validation



SPLICE



ABAQUS FE

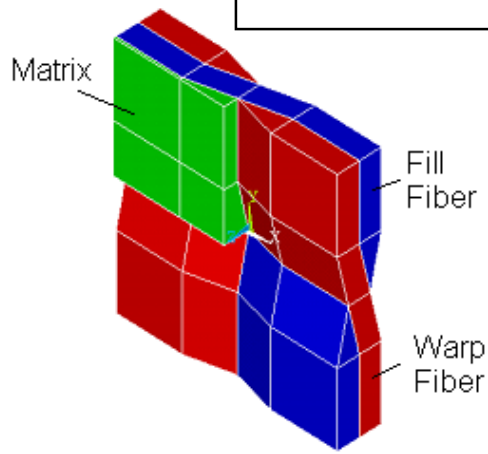


SUBLAM

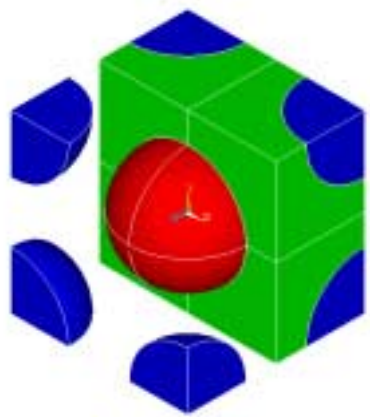
Failure Modeling:
Multicontinuum Theory

- MCT is a theory for obtaining constituent (fiber and matrix) stresses from composite stresses
- MCT based failure analysis can be applied to composite structures using commercially available ANSYS or ABAQUS
- MCT analysis can be run with almost no time penalty, since constituent properties are determined before hand.
- Uniaxial, woven, and particulate unit cell models are available.

MCT Weave Model



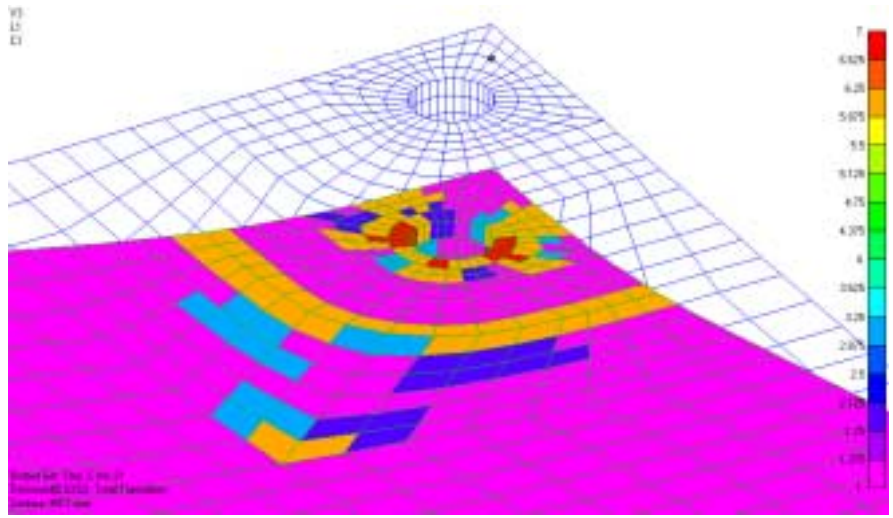
MCT Particulate Model



Failure Modeling: Multicontinuum Theory

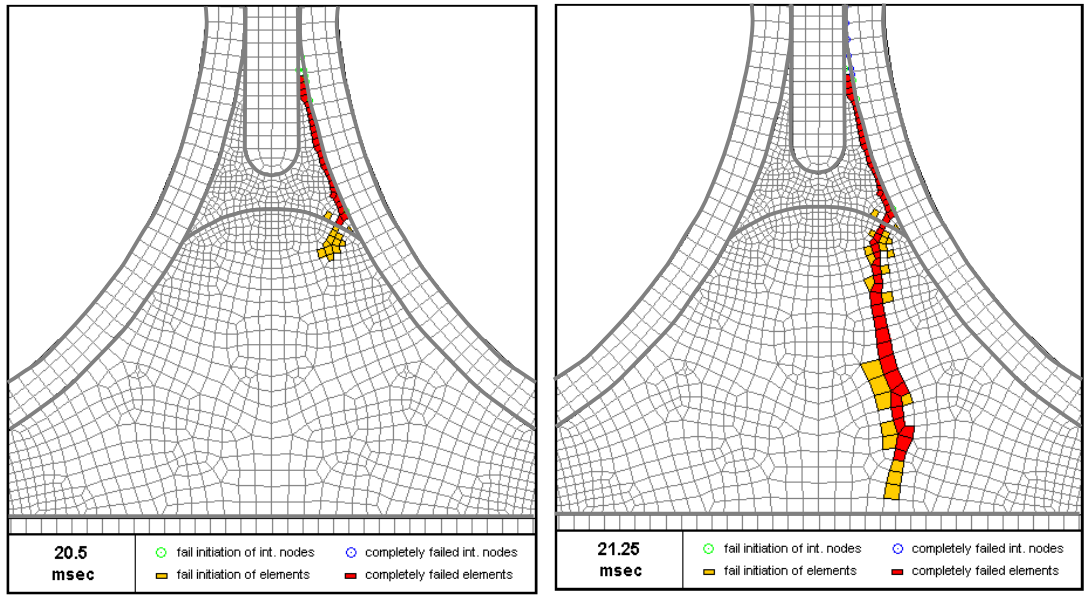
Example: Thick GRP Shell Structure

- Original FEM analysis over-predicted structural strength by 57%.
- Initial MCT based FEM analysis predicted structural strength within 2%.
- MCT analysis also showed the initiation of damage in a region unobservable during testing, underneath the bolted test fixture.



Failure Modeling: Composite Dynamic Failure Prediction Tool

- Dynamic Failure Analysis
  - Discrete Crack Model
  - Delamination
  - Fillet Cracking

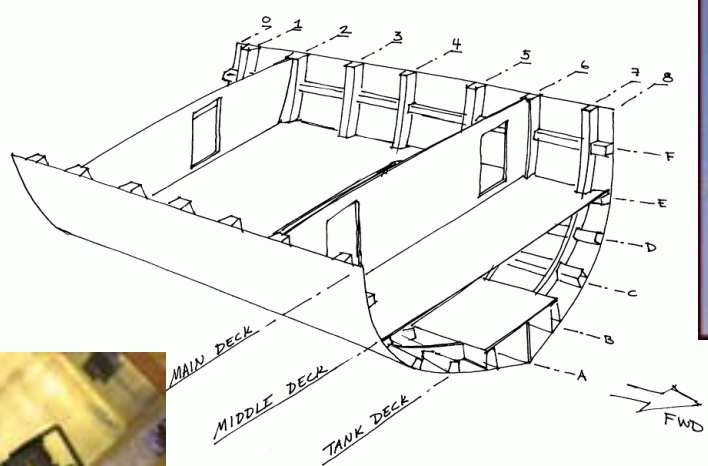


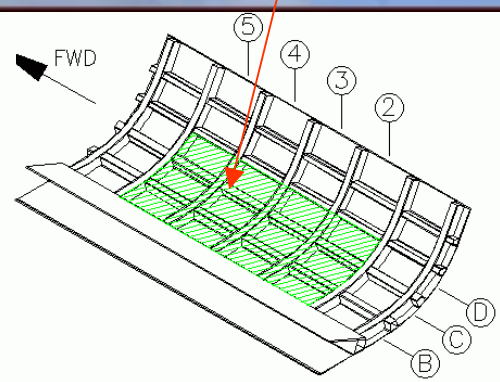
Composite Damage Assessment:
Composite Corvette Hull – Shock Test

Ultrasonic Inspection of the hull concentrated on the hat section stiffener tabbing and hull shell between frames 2 and 6 and longitudinal stiffeners B and E (between tank and middle deck).

- This area experiences the highest loads during the initial moments of the shock event.
- Stiffeners tabbing prone to damage under shock loads.
- 100% of the internal hat stiffeners bond to the shell was ultrasonically inspected.
- 63 Data points were recorded and are available for review.

<u>Note</u>: Hat stiffeners were not inspected





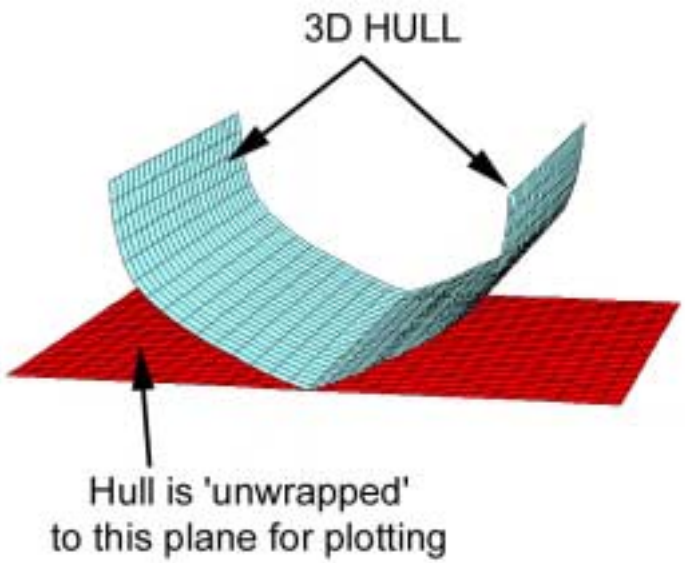
Composite Damage Assessment: SIDER Inspection Method

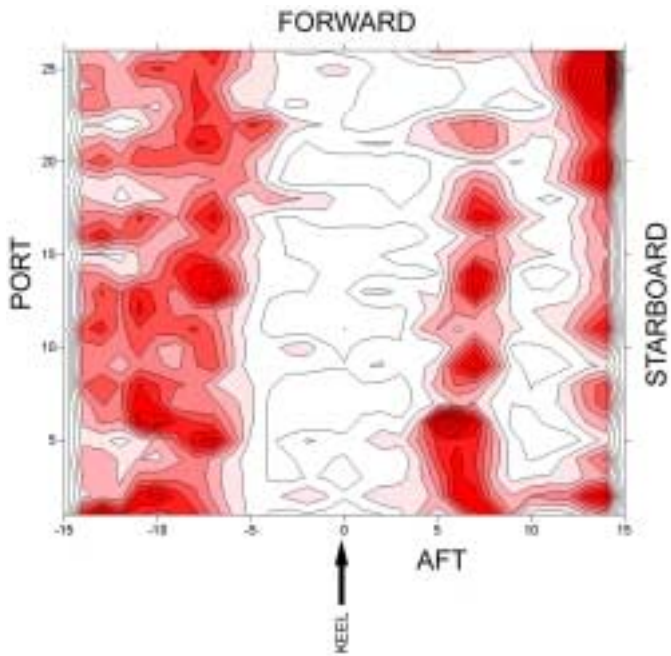
Structural Irregularity and Damage Evaluation Routine

- SIDER is a vibration-based inspection method
  - Vibration waves are totally invasive
  - But not intrusive
- SIDER is designed for the rapid inspection of large structures
  - A single inspection locates areas where there is structural variation/inconsistency. These are places with:
    - Designed (deliberate) stiffness changes
    - Manufacturing anomalies
    - Service-related damage
  - Before/After testing helps identify and locate in-service damage
- Detailed (but time consuming) inspections, e.g., UT and laser shearography, can be focused only on regions identified by SIDER

SIDER Inspection of Shock Tested Composite Corvette Hull

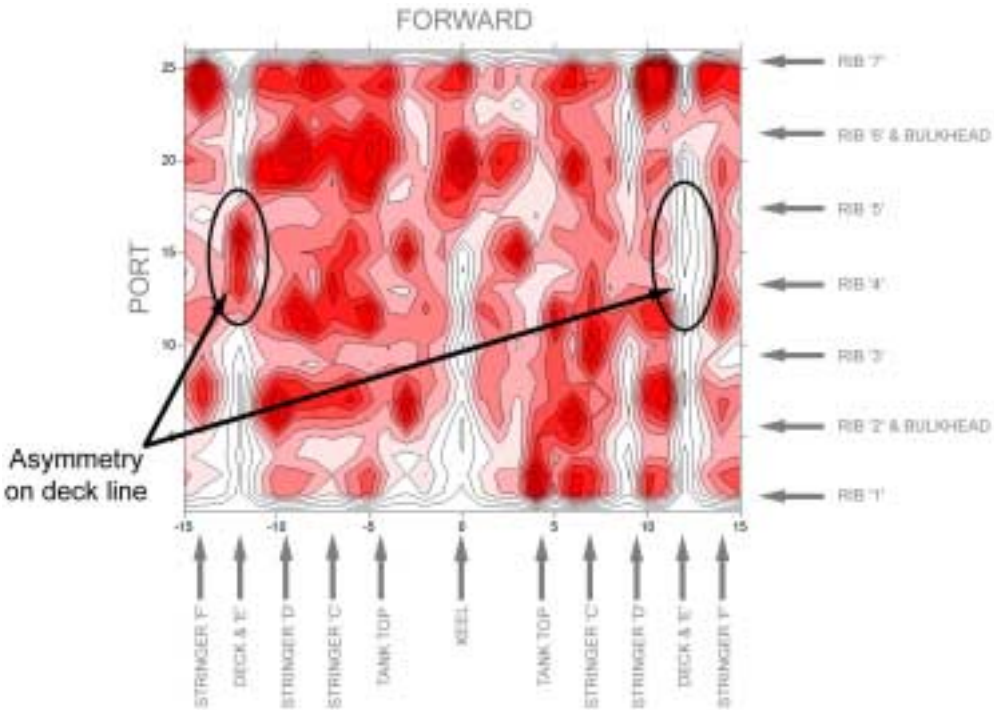
- Structural Integrity and Damage Evaluation Routine (SIDER) inspection performed prior and between shock tests
- 5 accelerometers used
  - 2 port side
  - 2 starboard side
  - 1 top deck
- Tuned, instrumented midsize sledge hammer used for excitation at 1022 predetermined points
- 4-1/2 hours to inspect whole structure





Pre-Shock SIDER Results

- Single pre-shock SIDER located some structural problems
  - Deck line debond
- Looking for changes after shock testing
  - Changes relate to damage
  - Damage can both increase and decrease structural uniformity
    - Local damage causes more flexibility
    - Stiffener debond can cause more homogeneity

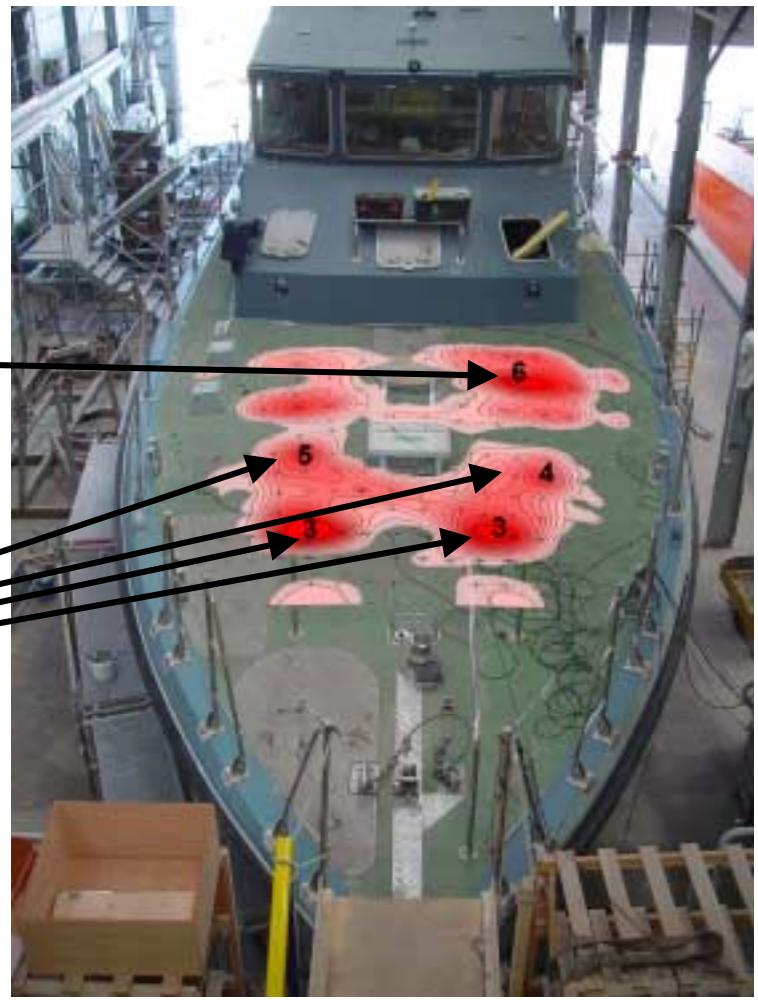


SIDER Results - Port/Starboard Analysis

- Single SIDER test of forecastle only
- Located a number of structural features

Structural bulkhead ends

Penetrations (deck prisms, vents)



Composite Structural Collapse: Corvette Hull Bending and Collapse Tests

Hull # 1: LTC-Prepreg

- **Very poor quality hull**
- **Insufficient Joints/Connections**
- **Warm-up / Calibration Test Specimen**

Test completed Aug 2002

Hull # 2: VARTM/Scrimp™

- **High quality hull construction**
- **VARTM Joints/Connections**
- **Full Validation Test Specimen**

Test completed July 2003

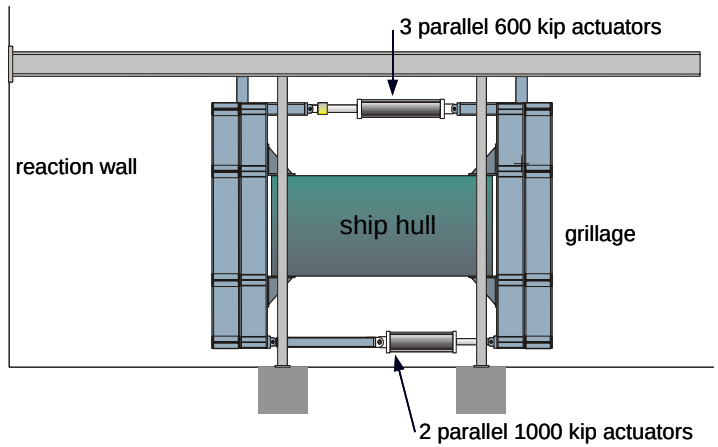
<u>Dimensions</u>: 28’ L x 20’ W x 10’ H, ~ 20,000 Lbs

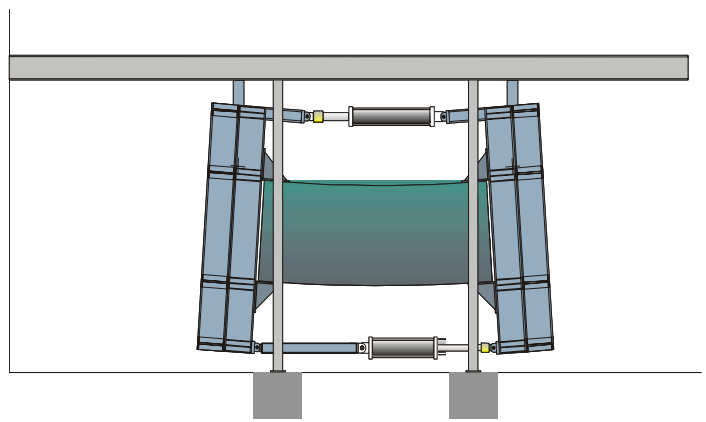
Composite Structural Collapse: Corvette Hull Bending and Collapse Tests

Objectives

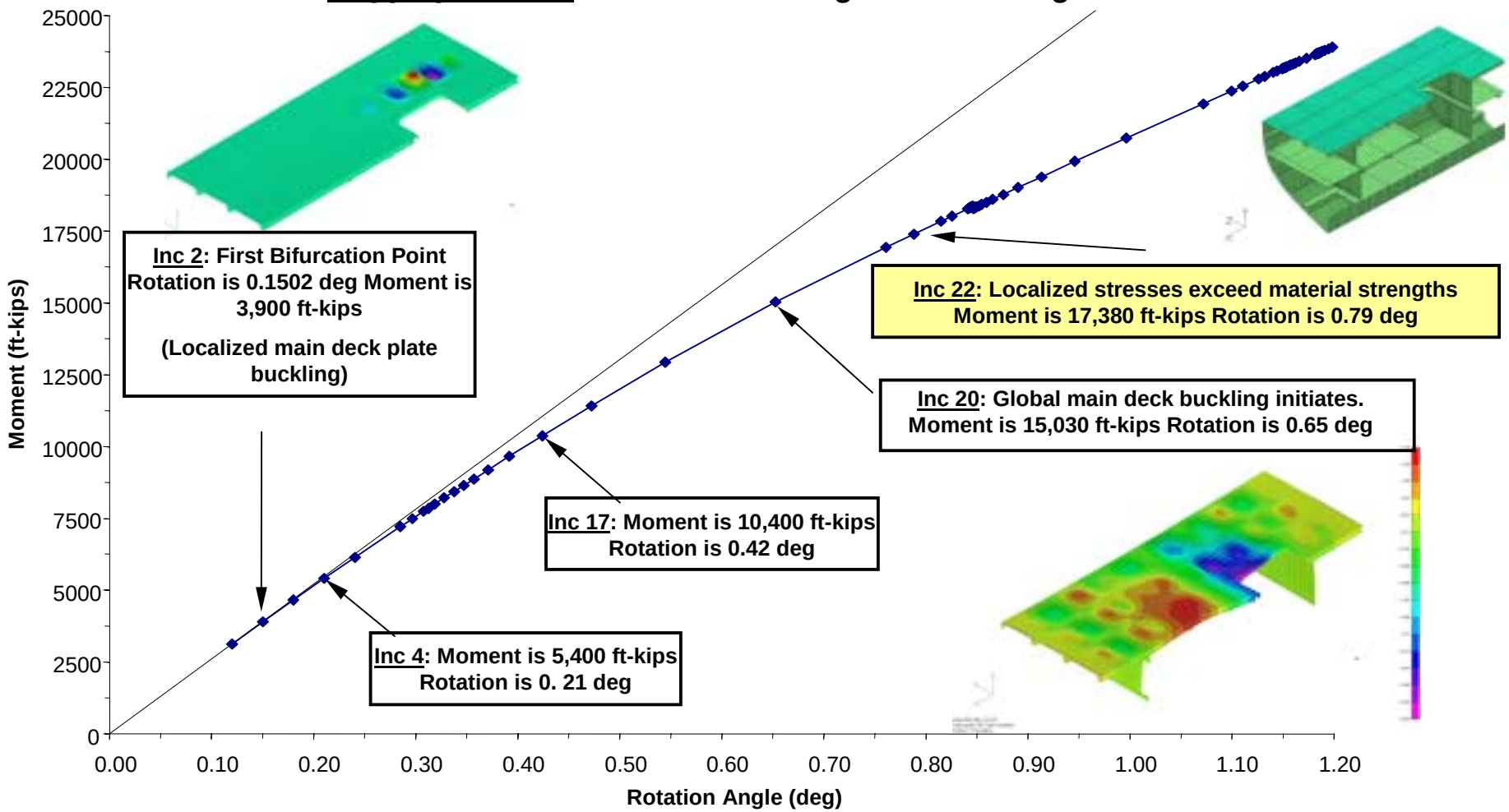
- **Design, fabricate and assemble a test fixture for testing 1/2-scale composite ship hull structures**
- **Conduct elastic hull-girder bending test under hogging and sagging conditions**
- **Conduct hull ultimate collapse test under sagging mode**

Grillage and Attachment Beams
(Lehigh University ATLSS)





Composite Structural Collapse: Corvette Hull Buckling Response Predictions



Summary

- **The Structures and Composites Department of the Carderock Division offers full service composite structures R&D including:**
  - Manufacturing Process Development and Support
  - Material Test Method Development
  - Material Environmental Pre-Conditioning Method Development
  - Structural Design and Analysis
  - Large Component Testing
  - Failure Model Development
  - Structural Damage Prediction
  - Unique Damage Assessment Capabilities
- **Focus is supporting the "wet" Navy including:**
  - Thick Section GRP Composites for Submarine Applications
  - Glass and Carbon Sandwich Structure for Surface Ship
  - Low Cost, High Quality Fabrication Methods